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“Breakthroughs” for a Green Economy? Financialization and Clean Energy Transition

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Reimagining energy infrastructures for the 21st century increasingly means choosing between competing economic futures, a dilemma that is now provoking conflicts across many places and realms. In the United States, one critical clash is unfolding among tech sector advocates for a clean energy transition, as U.S. cleantech has worked to regroup from Silicon Valley’s failed clean energy manufacturing push of the late 2000s and to navigate an ongoing solar trade war with China: about what that transition might look like, how it might be achieved, and, critically, what economic sectors and rents might emerge from it. One set of entrepreneurs and venture capitalists argues that “breakthrough” clean energy technologies are needed to produce an energy transition and to bolster U.S. economic power into the 21st century. Meanwhile, a competing set prioritizes deploying existing technologies and infrastructures at scale. The latter argues that new *kinds* of innovation can accomplish this task, and in the process defend embattled U.S. hegemony: notably, so-called *financial* innovation, and new articulations between finance and high tech. This debate has major implications for the nature and global politics of a green economy.

Keywords: green economy; financialization; cleantech; infrastructure

1. Introduction

As political factions in the United States clash over the prospect of a clean energy transition, it has become increasingly clear that reimagining the country’s energy infrastructures for the 21st century means choosing between competing national economic futures. In the U.S. context, worsening conflicts with embattled fossil fuel industries and regions dominate much of this discussion, with new populism around the demise of U.S. coal only the latest, most confused – and recently most significant, in the wake of the 2016 Presidential election. However, fossil fuel industries’ rhetorical and institutional assaults on renewables, and clean energy supporters’ own recent organizing successes against fossil fuels (Knuth 2017), are far from the only face of this struggle. In this paper, I will engage a debate that I argue has profound significance for the future of clean energy in the United States, the nature of the green economy that energy development might produce, and the shape of U.S. power within 21st century capitalism. In the late 2000s and early 2010s, U.S. clean energy advocates experienced a profoundly confusing phenomenon, one

that is still reverberating through the industry: Silicon Valley led a would-be boom in “cleantech” innovation and manufacturing that lapsed into an embarrassing failure, one that still tarnishes the sector in the minds of many. Almost simultaneously, renewables recorded a wave of staggering successes: the country saw a surge of solar and wind energy deployment, and a radical cheapening of these technologies. Through this ongoing wave of infrastructure development, renewables have achieved cost-competitiveness with fossil electricity sources in an increasing number of markets across the country. This highly disparate experience has provoked contrasting – and competing – visions for the future of U.S. clean energy, and a clean energy economy.

On the one hand, as I will discuss in the first section of this paper, entrepreneurs and venture capitalists that had backed Silicon Valley’s failed cleantech boom were profoundly frustrated in its wake. With new self-appointed spokespersons like Bill Gates, in the mid-2010s they set out in search for an explanation of what had gone so wrong – and how it might be remedied to advance the sector moving forward. They expressed a keen sense of opportunity lost for U.S. companies to develop “breakthrough” renewable energy technologies to transform the sector and the U.S. economy into the 21st century. Moreover, as I will explore in the second section, they sought governmental protection against a competitor their past experience equipped them poorly to fight, as China rose to become a global clean energy manufacturing leader not on the strength of new research breakthroughs but on the mass production and deployment of long-mature technologies – ones that the United States had played an important role in developing, but had chronically neglected in deployment.

On the other hand, as I will argue in the third section, a competing set of entrepreneurs and financiers saw in the U.S. wave of renewable energy infrastructure deployment in the 2010s – and the cheap imports that helped enable that boom – a major new opportunity. They maintain that the United States has not lost its chance for genuine clean energy breakthroughs, nor for the international comparative advantage and monopoly rents, private and public, these innovations might bring. Rather, U.S. public and private actors should reimagine (more accurately, *continue* to reimagine) what “counts” as innovation, within cleantech and full stop. They have proposed ways by which Silicon Valley entrepreneurs might remake cleantech in information technology’s

image, a “Cleantech 2.0”. Crucially, within this broader rethinking they have framed *financial* innovation, and a rising “fintech” sector, as a legitimate and necessary source of breakthroughs in renewable energy deployment – arguments made before the late 2000s financial crisis for financial productivity, financial engineering, and U.S. financial hegemony returned in a green, high-tech form.

With this paper, I take up a debate that has become central to the politics of energy transition and its articulation with green economic development in and beyond the United States, but that has been surprisingly neglected in critical scholarship. In the United States, questions of the *sufficiency* of energy, its basic affordability and security, have receded in domestic energy politics – not the case when modern clean energy technologies were developed in the 1970s. Instead, proponents frame renewable energy development and broader clean energy interventions¹ as a vehicle for novel forms of innovation, economic development, and political economic power – would-be qualitative transformations and secular expansions within a global capitalist economy. This narrative has built on preexisting discourses of high-tech “disruption” (Knuth 2017) and rejuvenated U.S. hegemony, including decades-old arguments for a “service economy” and “New Economy” to be led from innovative urban-regional economies like Silicon Valley. As I will argue, it has simultaneously inherited, and stands to further, a longstanding “financialization” of these performative visions of U.S. innovativeness and sustained power (Krippner 2011, Christophers 2013).

Theoretically and methodologically, this discussion advances new political and cultural economic scholarship on green economic development (and clean energy transition as a central project of that development), financialization, and, crucially, the deepening articulations between these contemporary processes (Georgeson et al. 2014, Baker 2015, Bracking 2015, Castree and Christophers 2015, Knuth 2016, 2017, Kennedy 2018, Langley 2018). I argue that the tech and infrastructure debates explored here present a distinct and significant face of broader financial sector interest in the green economy. I foreground both the narratives through which competing interests are making their case today, and the longer-term structural conditions and discourses that have helped shape these arguments. Particularly, I focus on a specific instantiation of today’s debate provoked by Bill Gates’ formation of a so-called Breakthrough Energy Coalition in the

lead-up to the 2015 Paris climate talks – a move that prompted critics to articulate competing versions of cleantech’s future. In contextualizing this contemporary debate within broader political economic transformations, I build upon work by geographical political and cultural economists (Caprotti 2012, 2015, Mulvaney 2013, 2016, Davies 2013, Knuth 2017), economic sociologists and innovation theorists (Block and Keller 2011, Krippner 2011, Mazzucato 2015) and science and technology (STS) scholars, particularly those working within the emerging cultural political economy of research and innovation (CPERI) (Birch 2017, Goldstein and Tyfield 2017).

2. A Breakthrough Energy Coalition? U.S. “Breakthrough” Debates in the 2010s

In the lead-up to the Paris COP21 climate meeting in 2015, Bill Gates and two dozen other tech and finance billionaires announced a bold investment commitment for climate change mitigation: they would collectively dedicate billions of their private funds to the development of “breakthrough” clean energy technologies, profoundly novel innovations to transform (and “disrupt”, e.g. Knuth 2017) energy production and use in the 21st century. Gates, who spearheaded the formation of this Breakthrough Energy Coalition, took a lead role in representing its mission (e.g., Bennet 2015, Gates 2015, Gates and Gates 2016, Pontin 2016). The Coalition demonstrated a faith in the power of the private sector and so-called angel investment long familiar from narratives of Silicon Valley’s success, as both private and public actors promoted its “open” model as the heart of the U.S. innovation system. Unusually, however, the Coalition also appealed to *governments’* role in technology development – a role that venture capitalists, entrepreneurs and policymakers have ignored and undermined for decades, as the rise of neoliberal economic thought since the 1970s and its successful attack on the Keynesian developmental state made overt U.S. industrial policy increasingly politically intractable (even as “hidden” industrial policy in diverse forms continued and even intensified) (Peck and Tickell 2002, Block and Keller 2011, Mazzucato 2015, Goldstein and Tyfield 2017).² Gates and others billed the Coalition as the private sector counterpart to Mission Innovation (which Gates also helped coordinate), a twenty-country commitment to double national clean energy research and development (R&D) between 2015 and 2020. Even as the 2016 Presidential election raised significant questions about the U.S. government’s willingness to honor its pledge,

Gates and company moved ahead with their private investment vision, shortly thereafter announcing a \$1 billion fund called Breakthrough Energy Ventures (Dolan 2016). With these initiatives, Gates furthered a particular vision of clean energy transition, one that he had advanced in various forms through the 2010s:

We need an energy miracle...a massive amount of research into thousands of new ideas—even ones that might sound a little crazy—if we want to get to zero emissions by the end of this century...Within the next 15 years...I expect the world will discover a clean energy breakthrough that will save our planet and power our world (Gates and Gates 2016).

Although many in the U.S. business press lauded the Breakthrough Energy Coalition's blend of billionaire philanthropy and enlightened investor self-interest, it has received a critical reception from a number of leading clean energy policy experts, entrepreneurs, and financiers (e.g., Dolezalek et al. 2015, Shah 2015, 2016, Liebreich 2016, Romm 2016). Many, like Romm, are established critics of Gates' energy 'miracle' argument, similar claims advanced by entities like the Breakthrough Institute (and see Goldstein and Tyfield 2017), and the basic philosophy of energy transition that underpins these narratives.³ In focusing on basic R&D and blue-sky energy breakthroughs, Gates and the Coalition downplay the significance of existing renewable energy generation technologies – especially wind power and solar photovoltaic (PV) infrastructures now being deployed at scale in the United States and globally. Critics argue that this preoccupation with *new* breakthroughs erroneously dismisses existing clean energy technologies, their ongoing improvement, and the dramatic progress now being made in their mass production and deployment. In other words, it misses a breakthrough that has already *happened*, as key renewable energy technologies developed in the 20th century finally come into their own. For example, the well-known cleantech entrepreneur Jigar Shah argues, “we already have the technology to solve climate change”. He elaborates:

The challenge with Gates's announcement is that while he and others are filling a real need, it is not the most pressing need...solar and wind are winning around the world not because of fundamental technological breakthroughs, but instead because after 30 years the banking sector is finally comfortable scaling up their use...we can always use more and achieve better. But for once we have to stop satiating the public with future talk around R&D and prove that [we] can do big things now. We have been training millions of people with the

skills necessary to deploy at scale for over 40 years. It's time to put them to work (Shah 2015).

Few of Gates' critics deny the need for ongoing R&D on clean energy technologies. Some, like Romm, point to a long-term personal record advocating for increased government spending on it (Romm 2016).⁴ However, they argue that given the inherent uncertainty of achieving radical technological breakthroughs and the historically long periods it has taken to mainstream even successful energy innovations, betting heavily on new R&D now rather than immediate deployment of mature technologies and their infrastructures risks a catastrophic delay on climate action – particularly given the potential longevity of energy infrastructures once built. Moreover, they caution that drawing investors' focus to R&D might divert needed funds from the more expensive proposition of large-scale deployment – a task that Bloomberg New Energy Finance estimates will require \$12.1 trillion through 2040 for electric power systems alone (Zindler and Locklin 2016). A similar argument applies to governments, who might be tempted to use “technology push” R&D supports to postpone undertaking more politically challenging “demand pull” deployment programs. The latter include feed-in tariffs promising favorably priced, secure contracts for renewable energy producers; renewable portfolio standards requiring a certain percentage of renewables in a power pool, with or without “carve-outs” mandating set amounts of particular generation sources or technologies; production and investment tax credits, depreciation allowances, and other renewable energy subsidies effected through tax codes; and a range of related subsidies, protections, and quotas – as well as the more indirect support provided by greenhouse gas emissions caps and negative pricing.

Often, those who favor deployment of existing clean energy technologies critique one of Gates' core assumptions: that new breakthrough technologies are needed to make renewables economically competitive with established fossil fuel energy sources. They point to dramatic increases in wind and then solar deployment since the mid-2000s, rapidly decreasing costs for these systems and the energy they deliver, and the dialectical relationships among all of the above. For example, Romm argues that in the 2010s:

We have seen that aggressive deployment of clean energy technology driven by government policies has—as was predicted—led to precisely the kind of game-changing cost-slashing

innovation that Gates mistakenly thinks happens primarily from basic energy research and development (R&D). For six years, Gates has claimed we were wildly under-investing in basic energy R&D. Yet, somehow the very thing Gates says he wanted—huge price drops in key low-carbon technologies (like renewables and efficiency) and key enabling technologies (like batteries for storage)—kept happening. The fact is that accelerated deployment policies around the world created economies of scale and brought technologies rapidly down the learning curve (Romm 2016).

In his intervention, Michael Liebreich, former CEO of Bloomberg New Energy Finance (BNEF) and now chairman of its advisory board, uses BNEF data to put numbers to these trends (Liebreich 2016). For example, he reports \$200-300+ billion a year invested in clean energy globally since 2008, a 50% drop in the levelized cost of onshore wind globally between 2009 and 2015, and an 80% drop in solar PV module costs between 2008 and 2015. Pointing to breakthroughs' potential for multiple phases (and causal factors), BNEF data shows that onshore wind and solar PV historically saw similar periods of rapidly falling costs after their initial introduction – from the mid-1980s to the late 1990s for wind and the mid-1970s to the mid-1980s for solar. These global average cost reductions leveled off somewhat afterward, before plummeting again from the mid-2000s to present as massively increased investment and deployment once again transform both industries (Liebreich 2016).

U.S. government agencies and national labs confirm these dramatic recent trends in renewables deployment and costs, and expand upon what determines those prices.⁵ The National Renewable Energy Laboratory (NREL) (2016) calculates that renewable energy made up 64% of all U.S. electricity capacity additions in 2015, and that national wind and solar electricity generation increased by a factor of twelve in the decade from 2005 to 2015.⁶ Meanwhile, the U.S. Department of Energy (DOE) (2015) reports drastic decreases in U.S. onshore wind and solar PV costs since 2008, in its case tracking whole-system costs for both utility-scale solar PV and distributed rooftop systems. This total adds to BNEF's PV module prices "balance of system" costs (e.g., for inverters, batteries, and other hardware) and "soft" costs (for financing, installation labor, permitting, and a range of other infrastructure development costs). Both balance of system and soft costs are nationally and regionally specific, and both also historically

have swelled the price of solar energy, as I will discuss more below. For wind, DOE (2015) reports that power purchase agreements for U.S. wind systems fell from 7 cents/kilowatt-hour (kWh) in 2009 to approximately 2.4 cents/kWh in 2014. For solar, the DOE quantifies the drop in solar PV module costs reaching the U.S. market: from \$3.57/watt (W) in 2008 to \$0.71/W in 2014. Factoring in non-module costs, U.S. solar systems nevertheless grew cheaper between 2008 and 2014: for utility-scale PV, from \$5.70/W to \$2.34/W; for rooftop PV, from approximately \$8.85/W to \$4.17/W.⁷

Hostility to overt industrial policy and a national mandate for renewables in the United States has meant that questions of “free” market competitiveness, and evaluative standards such as renewables’ ability to achieve electric “grid price parity” with fossil fuels, have dominated national renewable energy politics and breakthrough debates.⁸ Although U.S. renewable portfolio standards might require a certain percentage of all renewable energy technologies at the state level, and carve-outs go further in requiring that utilities procure a fixed amount of a particular energy resource, neither sets a price for this energy. In characteristic neoliberal fashion, these policies ostensibly leave such price-setting to the working of the market. Meanwhile, in actual practice, more and less overt, a broad range of government programs now subsidize renewables, while fossil fuels and nuclear energy use decades of their own far-greater government subsidies and supports to stack the deck against new entrants. I will argue in the next section that even as renewables increasingly do succeed in reaching U.S. grid parity (DOE 2015), market price remains a locus of strategy and debate. However, this new “cheapness” is a product of political economy as much as raw technological potential, no matter how thoroughly breakthrough visions attempt to “render technical” its politics (Li 2007).

3. Breakthrough Debates in Context: U.S. Renewables’ Turbulent History

To contextualize today’s breakthrough debate, quests for energy breakthroughs have a long history in U.S. renewables development – but a mixed record. In the early 2000s, Garud and Karnøe (2003) advanced an important critique of the U.S. breakthrough preoccupation. They argued that the United States had come to favor a “linear” model of renewable energy innovation, prioritizing basic science research in search of fundamental breaks with existing

technologies. Applying this philosophy, developers seek to commercialize innovations only after a long period of basic research and prototyping. This approach stands in contrast to quicker market deployment of more modest innovations, with iterative improvement via learning-by-doing. To cite one important success, the breakthrough model served the United States in its early development of solar PV (Knight 2011). Bell Labs first demonstrated the silicon solar PV cell in 1954 – a dramatic departure from existing electric generation methods. Then far too expensive for private use – especially in competition with heavily subsidized nuclear power and cheap oil – for the next two decades solar PV relied on U.S. government R&D for further development. Historians of U.S. solar show that the United States initially accomplished this task via a quintessentially breakthrough-oriented program, outer space exploration. The National Aeronautics and Space Administration (NASA) and corporations under government contract developed PV technologies for satellites and other uses, improving and cheapening them in the process. Since the 1970s, U.S. government laboratories and their contractors such as the NASA Jet Propulsion Laboratory and U.S. Department of Energy labs have conducted basic research on solar energy – for example, dramatically increasing PV cells’ efficiency and improving manufacturing processes, as well as advancing thin-film solar PV technology (Knight 2011). These efforts did much to establish the base technologies now used in solar PV markets and manufacturing today, and to support future possibilities such as thin-film solar.

In contrast, the U.S.’s breakthrough model historically impeded its domestic wind power development, a sector in which new experimentation built upon a very old technology. In the midst of the 1970s energy crisis, the U.S. government, then fresh off the Apollo program and in search of a new grand challenge, proposed a Federal Wind Energy Program (van Est 1999, AWEA 2017). Through the late 1970s and early 1980s, this program, led by NASA and its established aerospace and electrical industry contractors (notably Boeing, General Electric, and Westinghouse) using National Science Foundation funding, sought to develop very large, light wind turbines. It targeted dramatic design breakthroughs – seemingly an easy task after U.S. successes with the space program. However, the initiative quickly suffered a series of disappointments, especially as aerospace-influenced designs failed under the high stresses of turbulent surface-level windflows (van Est 1999, Garud and Karnøe 2003, Mazzucato 2015). Meanwhile, ramping up a wind program of its own,⁹ Denmark adopted a radically different

approach: working with its domestic companies like Vestas to deploy rapidly and gradually improve far smaller, more “low-tech”, and, critically, more sturdy and reliable designs. Although the larger, higher-power output turbines originally envisioned by U.S. engineers have been realized today, pushing for an early breakthrough proved disastrous for the nascent U.S. wind manufacturing industry. In the 1980s California wind boom that inaugurated the modern renewable energy era, Danish turbine suppliers quickly outcompeted their U.S. counterparts. By the end of the boom, U.S. wind project developers like Zond overwhelmingly imported their turbines from Denmark (van Est 1999). U.S. wind developers have remained dependent on foreign imports since, sometimes overwhelmingly so (partly due to the U.S.’s long-uneven support for wind after it lost the 1970s-1980s manufacturing race).¹⁰ Meanwhile, capitalizing on its early lead in the United States and other markets (Garud and Karnøe 2003, Lewis and Wiser 2005), Denmark’s Vestas remains the world’s largest wind turbine manufacturer today.

However, the most immediate spur to Gates and company’s call for new breakthrough funding today is the U.S.’s failed cleantech manufacturing boom of the late 2000s, and an ongoing push to recharge and redirect the sector in its wake. Between 2006 and 2011, U.S. venture capital firms invested over \$25 billion in cleantech start-ups, many focused on renewable energy – and lost over half their money (Gaddy et al. 2016). Silicon Valley led the charge on this cleantech boom and bust, inspired by various developments in the early and mid-2000s – new attention to climate change following the release of Al Gore’s *An Inconvenient Truth* and California’s passage of landmark climate change legislation; activism from prominent venture capitalists such as John Doerr and Vinod Khosla; the seeming prospect of high oil and energy prices for the foreseeable future; high-profile initial public offerings (IPOs) for several solar companies in the early 2000s. Moreover, in the wake of the 2001 dot.com crash, venture capitalists required a new boom in *something* to maintain the industry. Entrepreneurs founded cleantech start-ups around a wide range of proposed clean energy breakthroughs and disruptions, financed by venture capitalists eager to get a piece of a promising new sector (Knuth 2017). A raft of solar manufacturing companies were particularly notable entrants. Start-ups like Solyndra inaugurated a fresh wave of experimentation, aiming to rethink solar electric generation from the ground up. They targeted thin-film solar technologies, novel PV module designs, and a range of other fundamental innovations in the sector. Thin-film was particularly attractive in that it

promised to reduce the use of silicon required for traditional crystalline solar PV (silicon was then experiencing a shortage), reduce manufacturing energy and time requirements, and thereby cut costs (Mulvaney 2016, Caprotti 2017).

Silicon Valley's mood was buoyant in the mid-2000s, with venture capitalists confident that they could disrupt established energy technologies and infrastructures, grow a green economy, and reap massive profits in the process (Luce and Steel 2015, Knuth 2017). However, the nascent cleantech sector quickly ran into trouble. The subprime crisis hit just as many start-ups were getting off the ground, stalling investment. The Obama Administration stepped in to partially fill the gap with a host of programs aimed at bolstering cleantech R&D and deployment, notably through the American Recovery and Reinvestment Act (ARRA). The administration's Advanced Research Projects Agency-Energy (ARPA-E) was one particularly significant breakthrough R&D program – clean energy's answer to the Defense Advanced Research Projects Agency (DARPA) for blue-sky military research. However, despite federal loan guarantees and other new subsidies, the would-be cleantech boom again began to collapse. New solar start-ups rapidly failed *en masse* (including particularly politically charged failures like Solyndra, which filed for bankruptcy in 2011), alongside many other manufacturing-oriented cleantech companies. Ultimately, the major share of the approximately 150 cleantech start-ups founded in Silicon Valley during the 2000s failed, albeit with important survivors such as Elon Musk's electric car manufacturer Tesla (Gaddy et al. 2016, Caprotti 2017). By the 2010s, most venture capitalists had let their 2000s-era cleantech funds lapse and turned their attention to easier and more profitable sectors, particularly a fresh information technology (IT) boom. In the lingering wake of this experience, Silicon Valley has been wary of new forays into capital-intensive cleantech manufacturing – with successes like Tesla so far exceptions that prove the larger rule.

Solar start-ups failed in the 2000s due to a range of factors – internal flaws in their technologies or business models, competition from fossil fuels made newly cheap by the U.S. unconventional boom, and so forth. However, the “solar trade war” that emerged between the China, the United States, and the European Union in this period was a key driver (Caprotti 2015, Mulvaney 2016). From the mid-2000s on, China has worked to become a leading player in global renewable energy manufacturing, destabilizing established geographies of production and

competition among the United States, Denmark, Germany, Japan, and other long-term leaders. With strong state supports, including in some cases state ownership, Chinese companies rapidly scaled up production of both wind turbines and solar PV modules, the latter using mature crystalline silicon technology rather than the experimental designs Silicon Valley start-ups were then attempting to introduce. The speed of this rise was staggering – China’s solar PV industry went from a \$2 billion industry in 2007 to a \$100+ billion one by 2014 (Mulvaney 2016).

As new Chinese renewables manufacturers targeted both China’s booming domestic market and international exports, they rewrote the rules of the global industry virtually overnight.¹¹ Chinese producers achieved significant economies of scale in their rapid ramp-up, and several quickly became globally ranked solar and wind companies (e.g., Broehl 2017, Colville 2017). Simultaneously, the speed of this expansion glutted the global PV module market. In 2012, Chinese companies produced 150% of world PV demand (Caprotti 2015). Between enhanced productivity and immediate market overcapacity, the global cost of solar modules plummeted – as demonstrated in BNEF’s numbers above. In the early 2010s, this price collapse overwhelmed many established PV manufacturers in both the United States and Europe, provoking a wave of bankruptcies. And it was a death knell for Silicon Valley’s crop of solar manufacturing start-ups. Meanwhile, although Chinese wind manufacturers have thus far focused on China’s own domestic market (Colville 2017), U.S. and European wind producers in a rapidly consolidating sector also increasingly brace for the entry of Chinese competitors.

In this turbulent context, breakthrough activism by Bill Gates and other U.S. tech leaders takes on new significance. As discussed in the first section, The Breakthrough Energy Coalition has emphasized the need for a stronger U.S. government role in developing breakthrough cleantech that can compete globally (Goldstein and Tyfield 2017). This narrative cedes ground to arguments that U.S. venture capitalists and small start-ups alone are poorly equipped to handle cleantech manufacturing’s typical capital intensity and long development periods: despite its common self-presentation, venture capital wants its high profits on a far less patient timeline. Critics had pointed out these deficiencies in the U.S. innovation system for years (e.g., Block and Keller 2011, Hargadon and Kenney 2012, Mazzucato 2015, Knuth 2017). However, the aftermath of the cleantech bubble saw Silicon Valley entrepreneurs and financiers internalize this

argument in new ways (e.g., Luce and Steel 2015, Gaddy et al. 2016) – if for some merely as a justification for abandoning cleantech for less socially beneficial investments. More broadly significant is the way that the Coalition’s call, in admitting flaws in Silicon Valley’s innovation model, contradicts neoliberal orthodoxy on industrial policy (and the U.S.’s supposed lack thereof).

Classified as industrial policy or not, the U.S. government is already pursuing steps to protect domestic renewables manufacturers. Both the United States and European Union have accused China of export “dumping”, using “unfair” state subsidies to allow its companies to price solar panels below the costs of production. Supporters of breakthrough solar technologies alleged that China’s mass production-and-deployment strategy had nipped promising innovations in the bud (Caprotti 2015, 2017). U.S. solar companies’ anti-dumping rationale was disingenuous in obvious ways, given the U.S.’s own (if less successful) subsidies.¹² Nonetheless, for the last five years, the United States has prosecuted an ongoing solar trade dispute with China and Taiwan through the World Trade Organization (WTO) – with the latest iteration set to be decided by the Trump Administration. Tariffs of 20-55% imposed in 2012 on China’s largest solar cell and panel manufacturers have been undermined by subsequent legal challenges and practical workarounds (Chinese manufacturers moving their factories to cheaper locations in Malaysia, Thailand and Vietnam) (Cardwell 2017).

4. From Cleantech to “Fintech”: Selling Breakthrough *Financial* Innovation

The strategies discussed above reproduce a common basic argument: that a global clean energy transition, and U.S. economic competitiveness within that transition, both require fundamental technological breaks and disruptions. We must thus ask the converse question of today’s breakthrough debates: who in the United States is instead advocating deployment-first policies, and why, beyond the appeals to the common good described in the first section (what steps are required for timely climate change mitigation)?

4.1 Cleantech 2.0: Innovation in Deployment?

First, arguments advanced by Romm (2016) and others today suggest the deployment argument's deeper roots in clean energy policy. A number of U.S. analyses have correlated successful renewable energy deployment programs with the development of domestic manufacturing industries and jobs. For example, Lawrence Berkeley National Laboratory researchers argued in the mid-2000s that:

The dominance of Denmark as a wind industry base is waning as countries like Germany and Spain, with larger exploitable wind resources and with higher electricity demands, show that stable, supportive government policies to promote wind energy utilization can be critical to both creating a market for wind and initiating the rise of local manufacturers producing world-class turbines (Lewis and Wiser, 2005, p. 1).

Most such analyses have used these economic “demand-pull” arguments to bolster calls for reform in the U.S. renewable energy deployment model. The U.S.’s lack of a federal renewable portfolio standard or other national mandate has made for an inconsistent patchwork of state level mandates. Moreover, although the federal government has subsidized renewables through the tax code for decades, the uncertainty of renewable tax credits since their inception – always established by Congress on a temporary basis, and frequently allowed to expire before being reinstated (so far) – has produced well-known boom-bust cycles in U.S. wind and solar development, and a general air of uncertainty. The federal government’s inconsistent support for renewables, and broader U.S. preoccupation with renewables’ competitiveness in a supposed free market, stand in contrast to Europe and East Asia’s more state planning-friendly varieties of renewable energy deployment. For example, in Germany’s famous feed-in tariff program in the 2000s, central government institutions required buyers to purchase renewable energy at an established above-market price, one set at a level capable of supporting nascent industries and phased down in a planned fashion as they mature. Scholars have credited Germany’s successful use of feed-in tariffs as a major factor in the country’s wave of solar infrastructure deployment in the 2000s, and the domestic solar manufacturing industry developed out of this boom (Knight 2011, Mazzucato 2015).

While China harnessed its own domestic renewables deployment in the rise of its solar and wind manufacturing industries, its success at making renewable energy a global commodity (Mulvaney 2016) (alongside other would-be global exporters, including the United States) increasingly threatens this model. Renewables have gone the way of other manufacturing in an era of free-trade dominance: with the prospect of supportive tariffs and other state protections for nascent industries formally off the table under the WTO regime, it is becoming increasingly difficult for would-be renewable manufacturers (companies and countries) to break into a consolidating industry. Meanwhile, countries like the United States cannot now expand their domestic deployment programs without raising the specter of “leakage” (Kammen 2015) – that in doing so they risk subsidizing the growth of foreign manufacturers as much as local ones, and worsening their balance of trade.¹³ This dilemma is the flip side of the rise of cheap renewable energy hardware in the 2010s, the U.S.’s related deployment boom, and policies in support of it – for example, the Obama Administration’s raft of deployment-oriented policies in and after the stimulus, and increasingly stringent RPS mandates in states such as California.

However, I argue that recent breakthrough debates are more than just policy prescriptions lagging this changing political economy. Rather, they exemplify a critical and growing trend in deployment-first discourses: attempts to frame the deployment process *itself* as innovative, and capable of generating fundamental breakthroughs. An expanding group of U.S. tech entrepreneurs and financiers, including several prominent critics of Gates and the Breakthrough Energy Coalition, are shifting established storylines around the division of innovative labor in the renewable energy development process. Historically, U.S. tech has imagined breakthroughs as an upstream phenomenon concerned with the advancement of basic technologies. Deployment was seen as the realm of project developers and project finance specialists – a body of practice aligned as much with infrastructure development and financing more generally as with renewable technologies *per se*, and not inherently “innovative”. U.S. tech interests, including Silicon Valley entrepreneurs and venture capitalists, are now working to overturn this assumption. In so doing, they are doing organizing work within tech communities, constructing a performative narrative that can attract entrepreneurs and investors to new innovation and investment frontiers. At the same time, they are making a bid for the broader legitimacy and

political power that a “high-tech” designation and an imagined capacity for breakthroughs has historically conveyed in the U.S. context.

In the aftermath of the cleantech bubble, a group of Silicon Valley entrepreneurs and investors sought to regroup by refocusing and reframing the sector around what Luce and Steel (2015) label “Cleantech 2.0”, and what practitioners have floated various names for, such as the “cleanweb” and “green Internet of Things”. Advocates claim that more traditional, “capital-light” areas of Silicon Valley and venture capital success in IT might nonetheless advance renewable energy development:

Venture capital...works much better for software-centric cleantech, or the ‘cleanweb,’ which includes less capital-intensive technologies occupying the intersection between information technologies (gathering, communicating, tracking, measuring) and cleantech (Luce and Steel, 2015, p. 188).

Some of Gates’ critics in the 2010s advance a similar vision. They highlight IT’s role in creating a “smart” and “digital” electric grid, one that can accommodate an influx of intermittent renewable energy from various U.S. regions – often far from urban load centers. Relatedly, they propose energy storage breakthroughs through innovative grid management (an alternative to batteries and other “hardware” solutions). But they also think bigger:

Where we really need billions to be spent is on the scaling up of applications and business-model innovations that build upon currently available clean energy technologies. Like the revolution in personal computing a generation ago, we’re at the dawn of the era of distributed intelligence in clean energy. Much of the hardware progress has been achieved. Now we must make it broadly available and easy to use; we need to connect and automate it and make it as ubiquitous and intuitive as the web and the smart phone...Energy is undergoing the same kind of transition that Microsoft led in the IT realm. It is moving from a centralized system to a distributed, networked set of consumer products and services—a transition critical to making these technologies globally affordable and impactful (Dolezalek et al. 2015).

4.2 “Fintech”: Financial Innovation for Clean Energy?

Significantly, however, programs for deployment-based innovation do not stop with IT: clean energy *finance* has become a central component of this broader vision of a revitalized, redirected, and low capital intensity U.S. cleantech sector, in and beyond Silicon Valley. Assessments of the state of U.S. cleantech in the 2010s increasingly emphasize the importance of “deployment finance companies” (Gaddy et al. 2016). Jigar Shah’s recent critique of Gates begins to elucidate what this financial brand of cleantech innovation might look like:

Construction companies [deploying cleantech infrastructure] need tremendous amounts of capital. The U.S. solar and wind industries alone will attract over \$60 billion in project finance capital in 2016. Energy efficiency, battery storage, electric vehicles, waste to energy, and other categories add even more capital. VCs have shifted their strategy to support technologies that improve the returns of project finance investors. Finance Tech makes deploying project finance capital faster, big data tools make building management more effective, tracking technology allows solar technologies to generate more production, and so on (Shah 2016).

Shah’s own entrepreneurial efforts further demonstrate a vision of this Finance Tech (“fintech”) for renewable energy deployment. As founder in the early 2000s of the solar project developer SunEdison and current president of a company called Generate Capital, Shah helped pioneer a business model he has variously called “solar as a service” and, more broadly, “infrastructure as a service”. At root, ventures using this approach promise clients no- or low-money-down financing for renewable energy projects. They achieve this cheap financing by experimenting with how renewable energy infrastructures might be legally owned (often in highly complex ownership structures), and what types of specially tailored financial benefits investors might derive from their development.

Exemplifying the model, SolarCity’s solar as a service-like brand of financial innovation has been particularly influential within U.S. cleantech. As a rooftop solar PV installer, SolarCity developed a third-party leasing/financing model that it marketed to clients: the company would install solar panels on residential roofs but retain ownership of the equipment, financing the costs of the system through selling households the energy produced on their properties. The pitch was

that households could obtain energy more cheaply than they could by purchasing panels outright, and with less hassle and maintenance. SolarCity's own benefits from this arrangement were more complicated. For one thing, it and installer-financiers like it were key beneficiaries of the global cheapening of PV modules in the 2010s – politics that aligned it against U.S. manufacturers in the solar trade war with China (Caprotti 2015).

More controversially still, SolarCity did not make its profits only from the sale of energy to clients or from the increasing cheapness of its base technology. Critically, the company set up its leasing model in a way that allowed it to appropriate the value of new renewable energy tax credits set up by the Obama Administration, ones nominally intended for households' own use. SolarCity acquired these tax credits from households, aggregated them, and on-sold them to large third-party investors searching for a legal tax shelter. In all, as one BNEF representative argued, "I would consider SolarCity not a solar company but a financial engineering company that has expertise in solar" (cited in Woody 2012). SolarCity and companies like it label (or euphemize) this organized appropriation of federal tax incentives as "tax-equity" financing, and market it as a genuine breakthrough in renewable energy development – the kind of innovation capable of filling the multi-trillion-dollar deployment "financing gap" that Zindler and Locklin (2016) quantify above.¹⁴

SolarCity has hardly been alone. A wave of similar green finance/fintech companies sprang up in the 2010s. Like SolarCity, they promised to help fill the renewable energy financing gap – generate creative ways of making money from clean energy infrastructure deployment, so that more private investors might be drawn to the sector – and to use distinct financial sector expertise to solve challenges in the deployment process.

4.3 Paradoxes of Green Financialization

Paradoxically, one of the central problems that these would-be financial innovations target is itself a product of financialization, defined here as the (re)growth of an increasingly large, powerful, profitable, and complex financial sector in the neoliberal era – a process that U.S. policies have directly supported via strategic de- and re-regulations (see e.g., Langley 2008, Krippner 2011, Christophers 2013 for more extensive discussions). More specifically, modern

U.S. renewable energy development grew up in an era in which the recession of the welfare state under neoliberal ideological assault and austerity was accompanied by rising financial sector interest in the production and management of infrastructure as a profit-generating enterprise (Torrance 2008, Ashton et al. 2012, O'Neill 2013, Langley 2018).

These structural transformations have shaped a central role for major financial institutions and finance sector profits in U.S. renewable energy development, in ways that now threaten the sector's future growth. As noted above, the cost of base technologies like PV modules is only one factor in the price of renewable energy systems. Analysts have long noted that the price of U.S. renewables, especially rooftop solar and solar PV in general, is unusually high due to "soft" costs – particularly the costs of *capital*. For example, the DOE (2015) reported that in 2014, Germany's rooftop PV system costs were, at \$2.13/W, about half the U.S. average – despite the two countries' similarly priced solar hardware (PV modules and balance of systems). As renewables' base technologies rapidly become cheaper, financing represents an increasingly high share of systems' costs to consumers (Feldman and Bolinger 2016) – and one that Gates-style breakthroughs in renewable energy hardware will not directly reduce. Moreover, financial players' ability to extract unusually high rents from renewable project development is not simply a matter of banks demanding higher fees for a risky new sector, as Shah's comment in the first section implies. It also has much to do with finance's growing ability to extract monopoly rents in a context of increasingly privatized infrastructure development.

Utility-scale renewable energy developments in the United States have from their inception in the late 1970s relied upon a specialized form of infrastructure financing known as project finance – indeed, analysts of project finance usually date its modern rise to that moment,¹⁵ although in the neoliberal era the tool took off across a broad range of infrastructure types and geographies (Finnerty 2007, Esty 2014, Langley 2018). In project finance's model, infrastructure developers create a legally separate company whose single purpose is to build and/or operate a large project like a solar farm or wind field. That company takes on an unusually high rate of debt, pledging to repay financial backers through revenue generated from the infrastructure itself – in selling energy and resources produced, often under a previously arranged contract like a Power Purchase Agreement (PPA); extracting user fees; and so on.

These single-purpose companies do not recycle revenue into new projects: once built, each functions as a passive machine for generating revenue for its backers. However, these boutique financing arrangements are not without their price. The usual complexity of each deal makes for expensive capital, one reason that project finance has typically been used only for very large infrastructure projects. These high costs now show up in the prices paid for U.S. renewable systems.

Peculiarities of the U.S. renewables policy context have made project finance even more costly for developers. With their use of tax-equity financing for residential solar, SolarCity and other installer-financiers merely expanded upon a practice that utility-scale wind and solar developers and investors had employed for decades. The U.S. government subsidizes utility-scale renewable projects primarily through the federal tax code: the federal Production Tax Credit (established in 1992, although with antecedents in the 1980s), the Investment Tax Credit (established in 2005), and related policies such as accelerated asset depreciation. Parent companies that developed the projects could in theory take these tax credits themselves. However, as shell companies that pass their revenue on to third party investors, they have a negligible tax burden. Instead, they use complex ownership arrangements to pass these tax shelter benefits too on to their investors – historically a small group of very large investment banks, insurance companies, and commercial banks capable of legally and profitably “mining” these tax savings (Schwabe et al. 2009, Bolinger and Feldman 2016). Investors may profit from tax shelter benefits far more than revenue from energy sales.

In the neoliberal era, investors have pursued lucrative tax-equity financing arrangements in both renewable energy and other areas of U.S. urban and infrastructural development: affordable housing development, using Low-Income Housing Tax Credits (LIHTC); community economic development, through New Market Tax Credits; and historic preservation, via Historic Tax Credits (Hackworth 2005, Deng 2013). These sectors’ shared mechanisms mean that their users often compete for the same tax equity investors, and renewable energy in particular has been dominated by handful of financial players. The pool included about twenty active institutions immediately before the 2008 financial collapse. In the crisis, the number shrunk to fewer than six – investment banks were simply not making enough profits to benefit from tax

equity-mining (Schwabe et al. 2009). This monopoly position has given financiers a troubling power to extract a high price for their capital – and did so even in the midst of the financial crisis, as the collapse allowed tax-equity investors still viable to charge even higher rents for their investment. Policymakers increasingly criticize this financing model as inefficient, costly, and damaging to ongoing renewable energy deployment (over and above its reliance on federal tax credits that may now be vulnerable) (e.g., Schwabe et al. 2009, Bolinger and Feldman 2016).

Crucially, the financial sector’s ongoing power is evident in the solution many U.S. commentators (private and public) espouse: one that arguably *further* financializes cleantech and renewable energy infrastructure development, in that it seeks a solution in financial expertise, financial innovation and asset creation, and new financial markets. The Obama Administration initiated one temporary “fix” in the financial crisis: loosening rules so that large corporations like Google could get in on the tax-equity market. Subsequently, proponents have sold asset-backed securitization as the future of financing clean energy infrastructure – adapting practices used for real estate investment, including in the production of the subprime bubble, for renewable energy infrastructure. Via securitization, lenders can on-sell loans to third party lenders/consortia or, preferably, secondary markets, freeing up capital that they can sink into new loans – a churning and expansion of capital that could theoretically expand indefinitely if the business model works. Advocates like Jigar Shah (2016) aim to turn renewable energy infrastructure into a standardized financial asset for institutional investors like pension funds to invest in. They claim that this securitization can thereby dramatically cut the costs of capital, performing a type of financialization that advocates have typically framed (for example, in the creation of modern stock exchanges) as a fundamental financial innovation, and moreover a species of democratization: turning to a broader pool of investors to lessen the power of individual rentiers.

SolarCity was once again a high-profile experimenter here. It began to issue asset-backed securities based upon its residential leases in 2013, and quickly expanded these issuances through the 2010s. However, also again it was hardly alone. Competing experiments and proposals include converting renewable projects into “YieldCos,” a form of publically traded company; tying renewable energy installation to property tax bills via Property-Assessed Clean Energy (PACE) loans; adapting real estate and infrastructure instruments such as real estate

investment trusts (REITs) and master limited partnerships for renewable energy infrastructure; and developing new solar-secured loans; among others (e.g., Lowder and Mendelsohn 2013, Feldman and Bolinger 2016). One instrument, YieldCos, already saw a major bubble in the mid-2010s – which when it collapsed in 2015 eventually sent SunEdison, Jigar Shah’s former company (which remained an ambitious experimenter in fintech), into bankruptcy.

5. Discussion and Conclusions

The U.S. cleantech debate explored here, and the broader intra-capitalist conflict that it expresses, remains live at the time of this writing. It is unlikely to be resolved soon. Adjudicating whether a clean energy transition might take shape through large-scale deployment of existing technologies and infrastructures – potentially with a raft of financial innovations to cut system costs and speed the flow of capital into the sector – or still requires fundamental technological disruptions and hardware breakthroughs can be performed with firm confidence only in hindsight. Rapid developments in areas such as energy storage today suggest the degree of ongoing technological flux in the sector, while global cleantech trade disputes and penalties, deployment frontiers, and geographies of production are themselves evolving quickly.

Simultaneously, Silicon Valley’s cultural and political economies present their own interpretive challenges. Announcements of bold new innovation and investment futures for the region are always part hype – the dream, only sometimes fulfilled, that such visions can take off and become self-fulfilling prophecies. For example, while Bill Gates and fellow Breakthrough Energy Coalition tech elites announced ambitious plans for their Breakthrough Energy Ventures fund in 2015, the fund has been slow to materialize. Its planned size has fluctuated and decreased – Gates alone originally pledged to commit \$2 billion of his own money, while subsequent pitches shrunk the fund’s total resources to \$1 billion. The fund’s organization and concrete plans also remained nebulous for years – only two years later have details begun to trickle in on what technologies it might invest in. Meanwhile, this and other Silicon Valley plans confront a U.S. political context that remains uncertain, and most recently actively hostile. At the same time, new sparks of capital-intensive cleantech such as Elon Musk’s attempts to translate SolarCity’s success into domestic solar manufacturing demand ongoing attention – especially

since Tesla formally acquired SolarCity in late 2016, billing itself as a broad clean energy company (while taking over issuance of solar asset-backed securities, at least \$485 million in 2017). Although the merged company's nature and future remain uncertain, it would not be the first Silicon Valley giant to emerge from a sea of failed competitors in a broader sectoral bust.

Notwithstanding these uncertainties and indeterminacies, the unfolding debate presented here sheds necessary light on how seemingly novel development visions for disruptive cleantech breakthroughs, clean energy transition, and a green economy have been in fact shaped – and in key ways constrained – by established economic strategies and imaginaries. First, Gates and the Breakthrough Energy Coalition have doubled down on a decades-long U.S. economic and political strategy, one that rose with rhetoric of a New Economy in the neoliberal era: chasing fresh technological breakthroughs in Silicon Valley and other high-tech clusters as a way to defend the U.S.'s “comparative advantage” in a globalizing world. U.S. tech companies and their financiers have long used fresh rounds of innovation, patents, and associated intellectual property claims to extract globalized monopoly rents for themselves and (depending upon their global tax shelter strategies) for the United States – even as their production chains moved abroad to China and other cheap mass producers (Mazzucato 2015, Christophers 2016, Birch 2017).

For decades, this vision of transnational power bolstered the U.S.'s embrace of neoliberal economic rhetoric and rollout of free trade policies. In this view, for policymakers and renewable project developers to pick mature renewable energy technologies over new U.S. innovations is a potential disaster for both private profits and the U.S.'s international economic position, as competitors increasingly dominate clean energy manufacturing, and the sector becomes ever more central within global economic development. However, even on its own terms the model has deep vulnerabilities. It demands aggressive policing of intellectual property claims in a world in which an ever-increasing share of global property value is immaterial and intangible. Moreover, it leans on emerging economies' willingness to stay content with mass production rather than seizing the reins of technological innovation and international rent extraction – a dubious proposition where today's China is concerned. In addition, it requires Silicon Valley and other U.S. public and private tech players to keep up with this treadmill of innovation: to produce a steady stream of disruptions and breakthroughs to maintain the U.S.'s edge.

Second, however, as competing entrepreneurs market new species of infrastructure finance as genuinely innovative cleantech for the United States, they too build on established U.S. economic strategy in the neoliberal era: attempts to reframe U.S. financialization and finance writ large as capable of innovation, and therefore potentially productive rather than simply extractive and parasitical (Christophers 2013). Many scholars of contemporary financialization have defined the process as centrally defined by its proliferation of new financial instruments, novel forms of valuable if intangible property based on practices such as securitization. In this framing, players like investment banks – or new financial start-ups – are not simply service providers. Rather, they are financial engineers, who use their unique expertise to produce innovative financial products such as asset-backed securities to sell to consumers and (especially) increasingly massive, consolidated institutional investors. This vision argues for ways in which contemporary financialization may function as a permanent secular expansion in capitalism rather than merely a temporary speculative period at the tail end of a genuine productive boom (Arrighi 2010). By extension, it works to legitimize financial specialization as a potentially durable source of global comparative advantage – and thus imagines a long-term future for U.S. financial hegemony, and U.S. financial institutions’ ability to extract and (again often only in theory) repatriate rents from a global economy.

Without comprehensively rehearsing arguments for and against financial productivity here, it is important to recognize new cleantech finance as a species of this broader claim, and a fresh attempt to bolster it by aligning finance with high-tech. Historically, advocates drew on the proliferation of intangible property forms associated with the rise of Silicon Valley and the IT sector, and discourses of a service economy and then New Economy to help legitimize and codify notions of financial products and productivity (Krippner 2011, Christophers 2013) (while venture capital’s centrality and high expected profits within tech imaginaries presented yet another face of neoliberal financialization). In the wake of the financial crisis, financial entrepreneurs’ doubling down on these associations with the tech sector has arguably done similar work – beyond cleantech, new start-ups now similarly sell IT-adjacent fintech ventures such as Bitcoin and other blockchain technologies as fundamental innovations within capitalism. If successful, these arguments may reframe how the United States defines its international

comparative advantage in renewables development: that deployment-first policies might be seen to advance U.S. economic growth and power even if basic technologies like solar panels and wind turbines are manufactured abroad.

Third, and finally, both of these competing visions for the future of U.S. clean energy innovation, the global green economy it might shape, and U.S. power within this economy contain a central silence. Even as Breakthrough Energy Coalition rhetoric flirts with a more overt U.S. governmental role in green industrial policy, it elides ways in which the federal government *did*, if fitfully, attempt a break with neoliberal tenets in the late 2000s. As the Obama Administration attempted more open industrial policy in and beyond stimulus-era supports for cleantech startups, it was attacked at once from the right, from actors hostile to both government planning and renewables full stop, and from the left for insufficient ambition and ideological and material commitment. At the same time, it attempted to advance a much more comprehensive Green Keynesian vision that, however partial and problematic in execution (Goldstein and Tyfield 2017), is notably absent from the models discussed here. While both programs advance proposals for recuperating U.S. private profits and national hegemony in a clean energy transition, neither has a real plan for green *jobs*, for the majority of the U.S. population who do not work in tech or finance.

As such, the models discussed here sidestep a fundamental question for the United States: whether the country can develop a green economy without a forceful break from neoliberal economic prescriptions, strategies, and hidden-at-best industrial policies – one that will be politically hard-fought, even as the 2016 Presidential election opened the door to new U.S. protectionism from the left as well as the right, and China’s green economy thrives through ignoring neoliberal screeds against industrial planning. As the visions explored here recast existing models of U.S. tech and/or financial hegemony, they continue to cede renewable energy manufacturing to China and other low-cost producers abroad – positioning most U.S. workers as consumers of clean energy technologies rather than producers of it. Breakthrough imaginaries do not promise “shovel-ready” manufacturing jobs and require a broader leap of faith – even if they do succeed in disrupting cleantech with new basic technologies, they cannot guarantee that their production will not simply follow other manufacturing abroad. When the question even comes

up for deployment-first alternatives, they typically propose low- and moderate-skill jobs in infrastructure construction/installation and servicing. These jobs have indeed been on the rise amid the U.S.'s wave of renewables deployment in the 2010s. However, like infrastructure and the construction sector more generally, they are subject to significant questions of job quality and durability – unlike renewable energy manufacturing, most infrastructure work disappears once construction is complete.

What the embattled Green Keynesianism and related “green collar” jobs calls of the late 2000s did get right in theory, and the debates presented here must consider, is that these more holistic considerations of U.S. economic interest matter *politically* in a context of energy transition. Populist political narratives in the 2016 Presidential Election contained many half-truths and fictions around the death of U.S. coal and how to apportion blame for it (coal has declined due to multiple internal and external factors, notably the rise of domestic natural gas). However, over the longer term rising renewable energy industries do ultimately threaten to overturn existing fossil fuel industries, working class and professional jobs, and regional production economies. They are under unusually high political pressure to produce *new* jobs that might replace sectors lost. As such, specters of a largely “jobless” green economy are a major obstacle to a U.S. clean energy transition, even if it that development serves the narrower and more abstracted versions of U.S. economic self-interest discussed here. Any serious industrial policy for U.S. cleantech, disruptive or in deployment, must ultimately confront this fundamental political economic challenge.

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¹ For example, around energy efficiency, green building and retrofitting, and other interventions not treated in depth here (but see Knuth 2016).

² A trend that has shaped energy-industrial discourses and policies across many contexts; see e.g., Tarasova (2018).

³ Gates' long-term support for nuclear energy and embrace of the climate skeptic Bjørn Lomborg have also drawn particular fire from Romm, Shah, and others. Indeed, Mulvaney (2013) excavates a historical renewable energy breakthrough versus deployment debate between Lomborg and Carl Pope, former Chairman of the U.S. Sierra Club, that anticipates many of the tech sector arguments explored here.

⁴ As Assistant Secretary at the US DOE in the mid-1990s, Romm oversaw the Office of Energy Efficiency and Renewable Energy (EERE), which he argues was then the world's largest program for low carbon R&D, demonstration, and deployment (Romm 2016).

⁵ Again focusing primarily on onshore wind and solar PV: hydroelectric generation has operated more or less at capacity in the United States for decades, and other sources such as solar thermal, offshore wind, geothermal, and biomass were more marginal in the US context in the period discussed.

⁶ According to DOE (2015), onshore wind made up 31% of all electric generating capacity added in the United States between 2008 and 2014 – and 46% of all new capacity added in 2015 (NREL 2016). Taking off later than wind, solar capacity additions leapt in the 2010s. NREL (2016) reports that in 2015, solar accounted for 15% of all new electric capacity added in the United States – primarily solar PV, although solar thermal power is also now seeing a wave of growth.

⁷ In practice, rooftop PV system costs vary considerably by place within the United States depending on factors such as local permitting policies (Knight 2011).

⁸ Although not alone. For example, wind and solar power's intermittency, and the current state of energy storage technologies and techniques for managing that flux, have provoked considerable technical debate – especially as energy storage itself has seen rapid transformation and cost declines in the 2010s (DOE 2015, Romm 2016).

⁹ In a broader wave of development from the late 1970s that also notably included Germany and the Netherlands (Lewis and Wiser 2005, Mazzucato 2015).

¹⁰ AWEA (2017) estimated 75% imported content in 2005, although in 2008 that had improved to 50%.

¹¹ See e.g., Gress (2015) for a broader picture of these emerging strategies.

¹² At the same time, India brought a dumping case against *US* solar manufacturers.

¹³ Unless they implement protections such as local content rules, themselves potentially vulnerable to free trade challenges.

¹⁴ See e.g., Knuth (2015), Langley (2018) for some of the diverse travels of this “financing gap” language.

¹⁵ Project finance has other antecedents as well, in early modern capitalism and, more directly, in revenue bond structures pioneered in US cities at midcentury, following high-profile experiments by actors such as Robert Moses in New York City. Oil and resource companies similarly adapted revenue bonds for their own infrastructure development (Finnerty 2007, Esty 2014).